LA-UR-25-26120
Approved for public release; distribution is unlimited.

Title: Monte Carlo simulations to design neutron transmission experiments at the DICER instrument at LANSCE

Author(s): Stamatopoulos, Athanasios; Devlin, Matthew James; Cutler, Theresa Elizabeth; Neudecker, Denise; Koehler, Paul E.; Kral, Dusan; Svoboda, Josef; Cooper, Andrew Leland

Intended for: MCNP user symposium, 2025-07-08/2025-07-11 (Los Alamos, New Mexico, UNITED STATES)

Issued: 2025-06-26

Los Alamos NATIONAL LABORATORY

Monte Carlo simulations to design neutron transmission experiments at the DICER instrument at LANSCE*

A. Stamatopoulos[1], M. Devlin[1], T. Cutler[2], D. Neudecker[3]

P. Koehler[1], D. Kral[1], J. Svoboda[1], A. Cooper[1]

1. Physics Division, Los Alamos National Laboratory, 87545, NM, USA
2. Nuclear Engineering and Non-Proliferation Division, Los Alamos National Laboratory, 87545, NM, USA
3. Computational Physics Division, Los Alamos National Laboratory, 87545, NM, USA

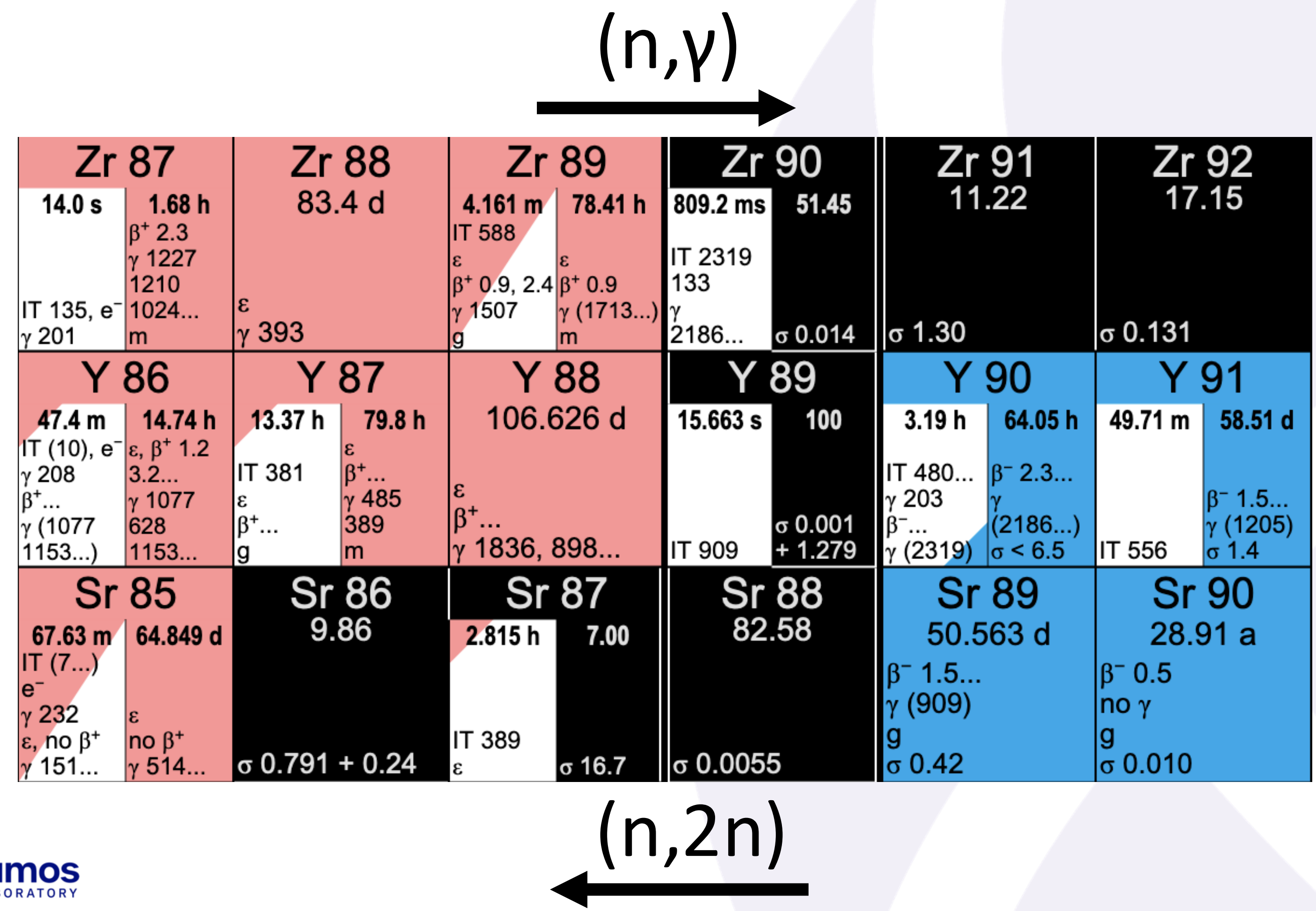
*Funded by
Los Alamos National Laboratory, Laboratory Directed Research and Development, Directed Research
Nuclear Criticality Safety Program

2025 MCNP User symposium, Los Alamos, NM, June 7th– 10th , 2025

LA-UR-25-xxxxx

The why

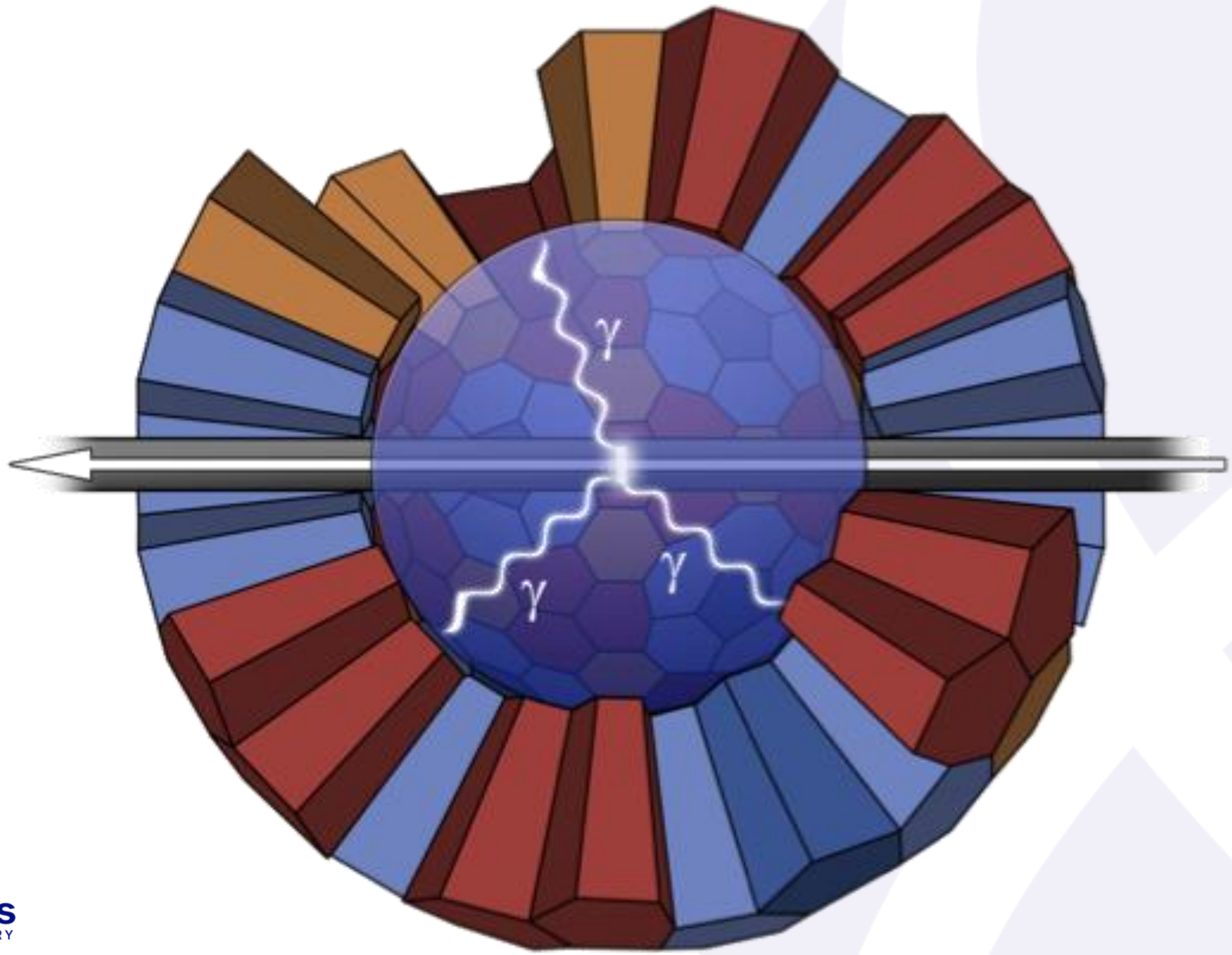
- Understand destruction/production rates of nuclei in a neutron field (astrophysics, radiochemical diagnostics, criticality safety)
- **Neutron capture (n,γ) "transforms" an element to the nearest element on the right**
- **Also (n,γ) is a "neutron poison" : it "steals" neutrons with <keV energies with high probability: important in modeling neutron population**



Los Alamos NATIONAL LABORATORY

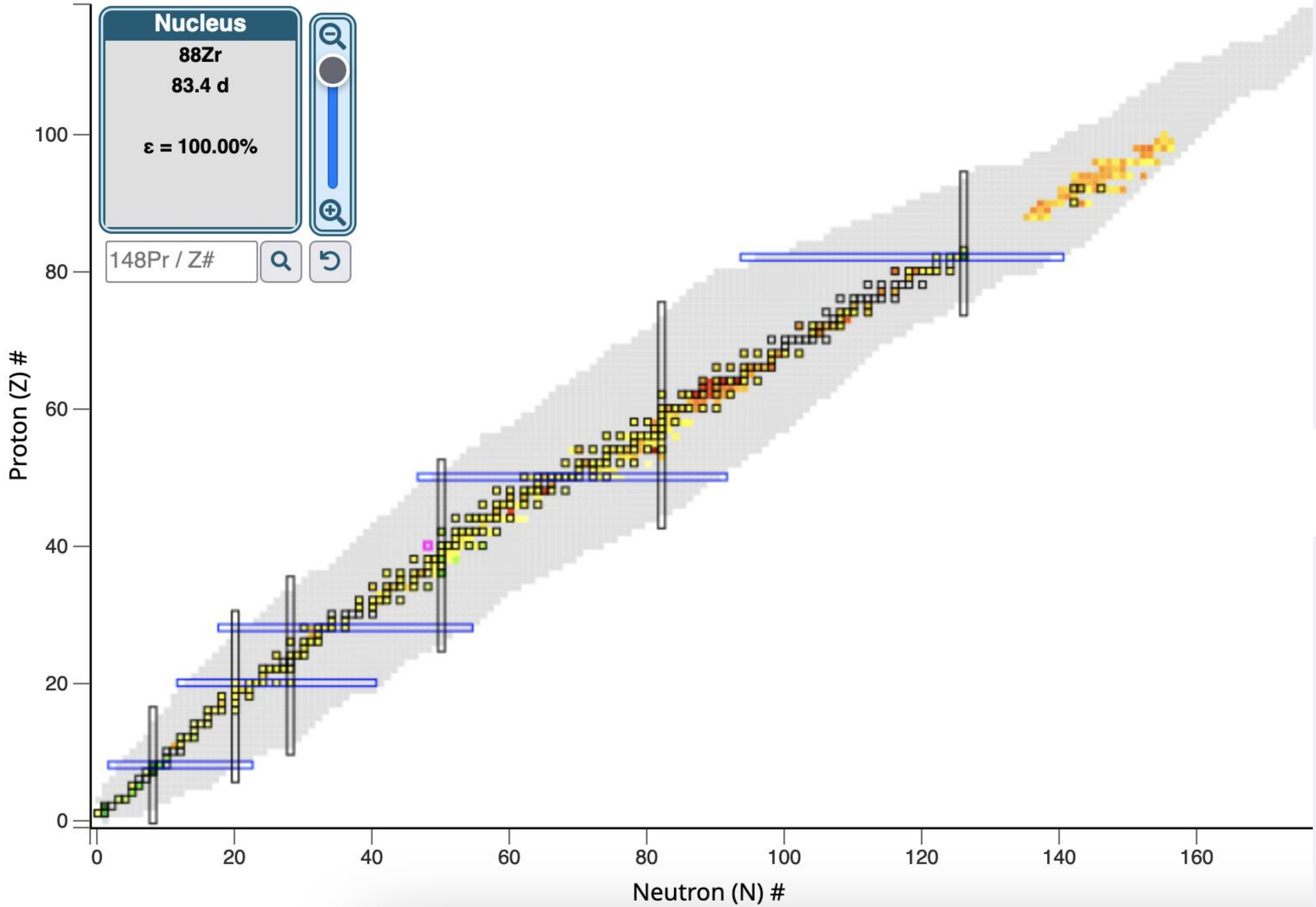
Direct neutron capture measurements

- Neutrons impinge on a sample
- Gamma detectors are close to the sample (order of cm) and detect the gammas from the de-excitation.



The what-we-know

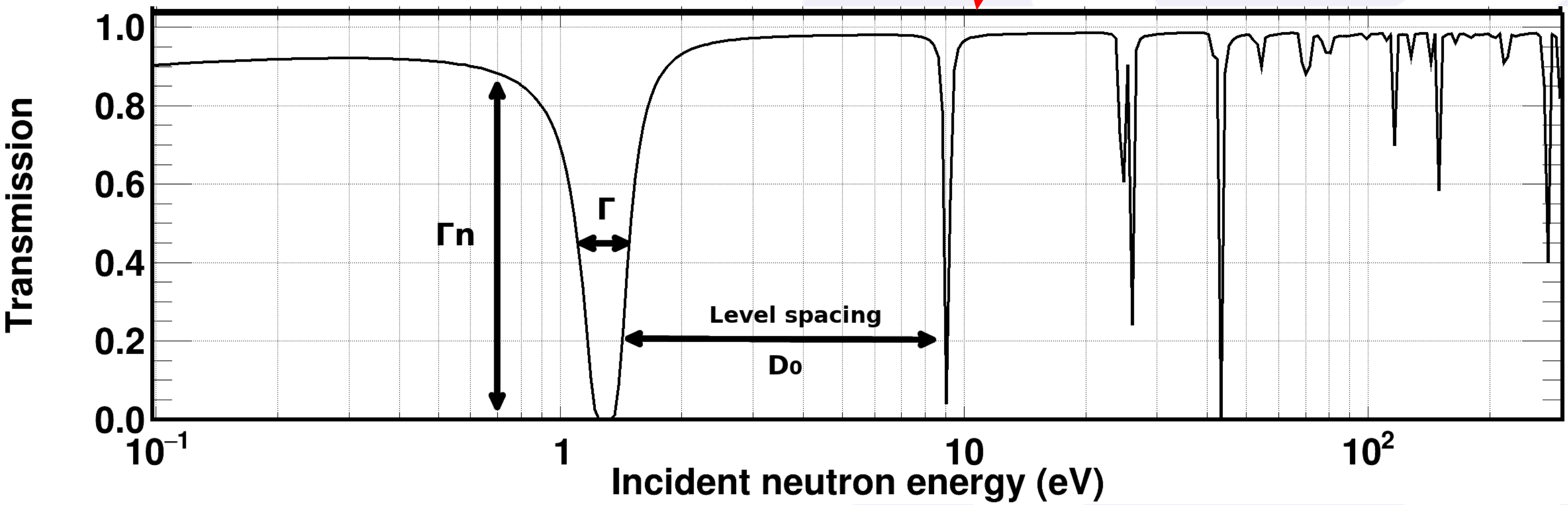
- Capture cross sections at thermal are known mostly for stable isotopes and actinides
- We need them for radionuclides as well



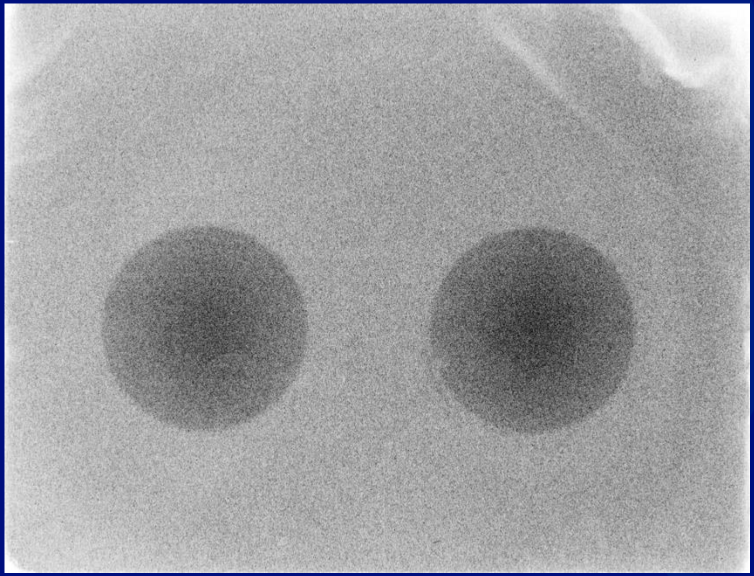
The technique in a nutshell

- We need 3 ingredients to extract the capture cross section, which accessible from a neutron transmission spectrum:
  - Neutron width Γ_n that is related to neutron scattering and can be extracted from the depth of a transmission dip
  - Total width Γ that is related to the sum of all the individual reaction cross sections and can be extracted from the width of a transmission dip
  - Level spacing D_0 that is related to the nuclear level density and can be extracted from the distance between consecutive transmission dip

$$\langle \sigma_\gamma \rangle = \frac{2\pi^2}{k^2} \frac{S_0 \langle \Gamma_\gamma \rangle / D_0}{S_0 + \langle \Gamma_\gamma \rangle / D_0} W = f(\Gamma, \Gamma_n, D_0)$$



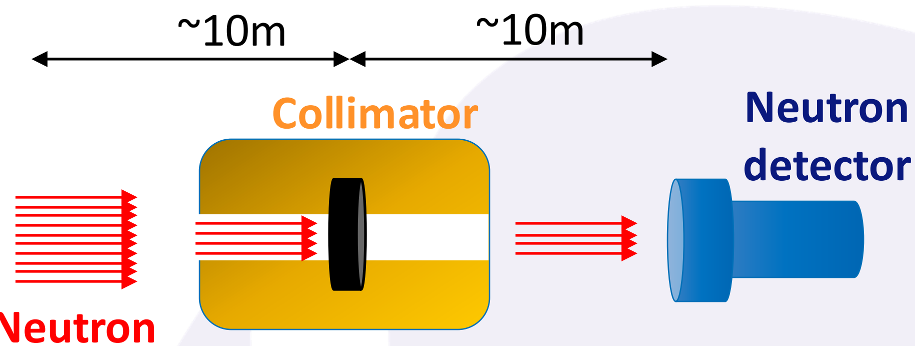
Neutron transmission measurements



Traditional transmission measurements: How to

- The neutron spectrum (C_{out}) and backgrounds (B_{out}) are recorded by a neutron detector (**sample out**)

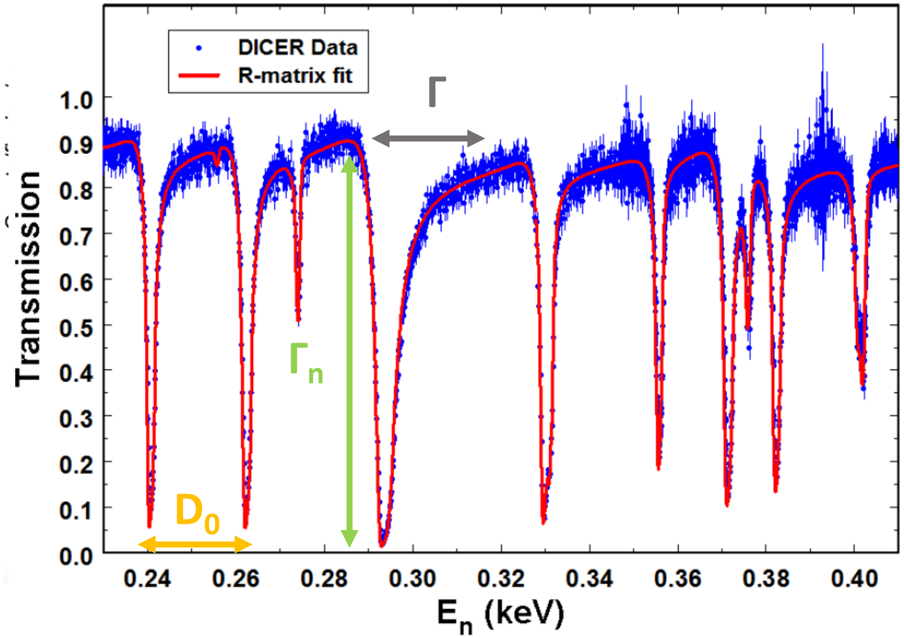
- A sample, (~cm in diameter), is installed and absorption dips appear (**sample in**)



- The transmission T is the ratio sample in/out

$$T = \frac{C_{in} - B_{in}}{C_{out} - B_{out}}$$

- Transmission measurements provide information on the total (Γ) and neutron (Γ_n) widths and the level spacing (D_0)



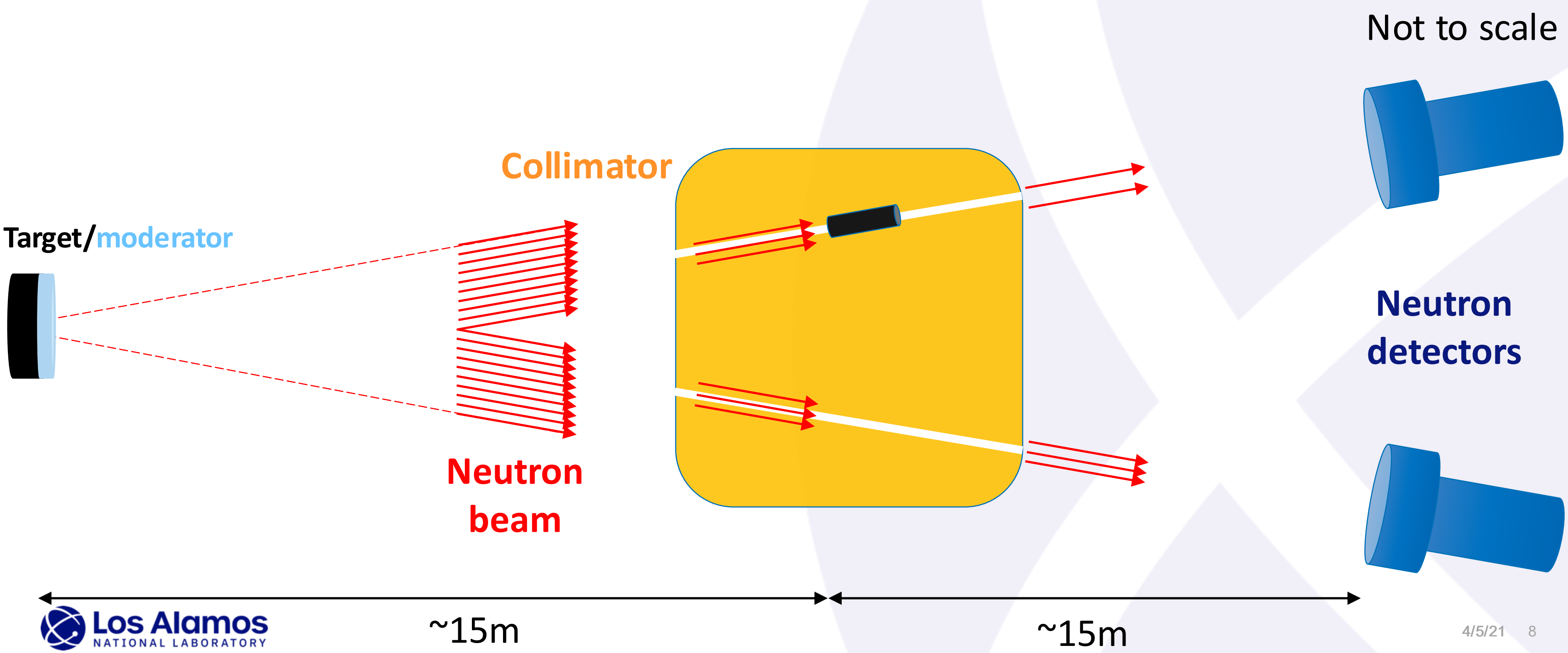
Γ : Transmission dip width
Γ_n : Transmission dip depth
D_0: Distance between transmission dips

$$\langle\sigma_\gamma\rangle = \frac{2\pi^2}{k^2}\frac{S_0\langle\Gamma_\gamma\rangle/D_0}{S_0 + \langle\Gamma_\gamma\rangle/D_0}W = f(\Gamma, \Gamma_n, D_0)$$

Los Alamos NATIONAL LABORATORY

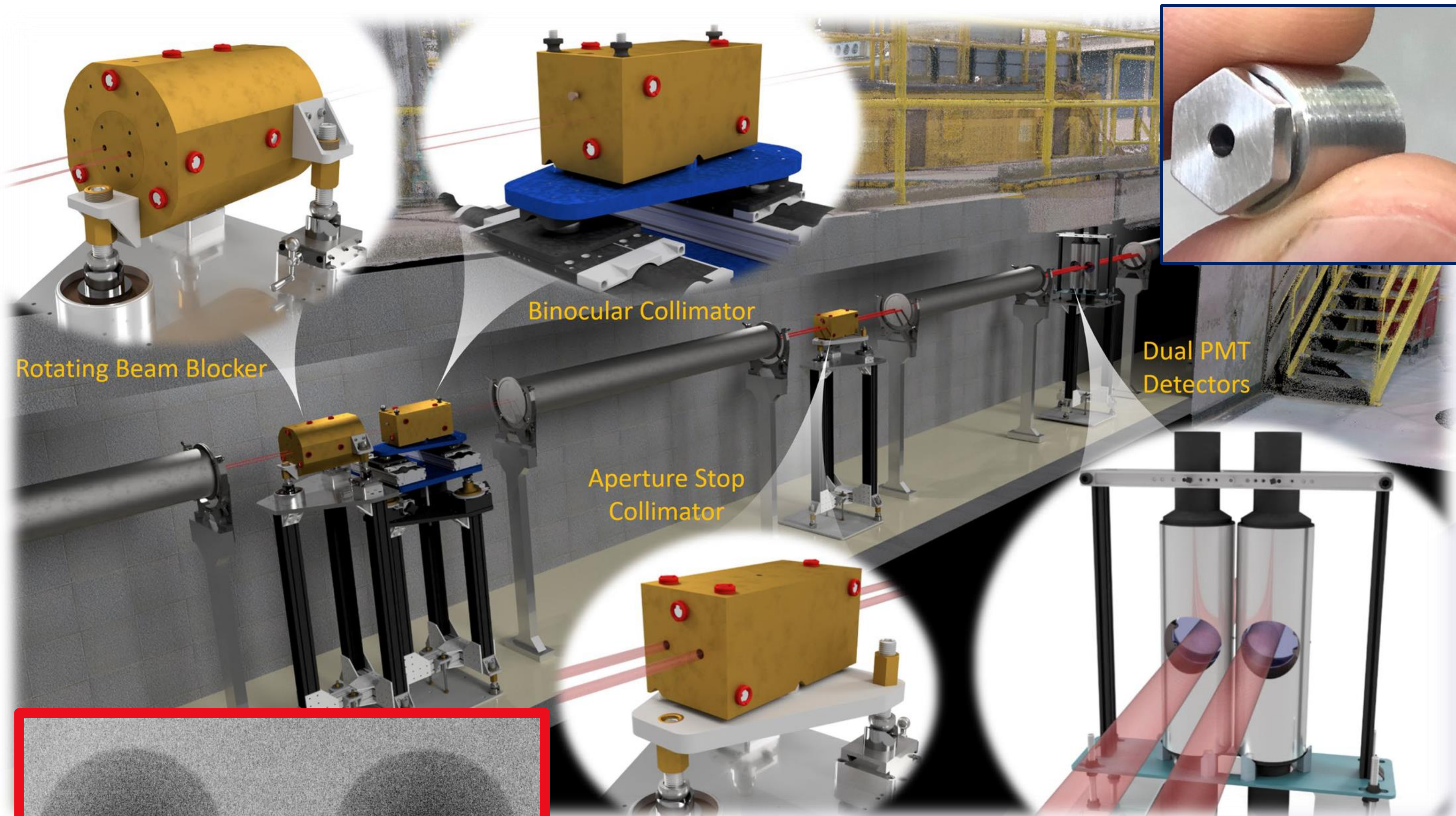
Non-traditional measurements: Binocular approach

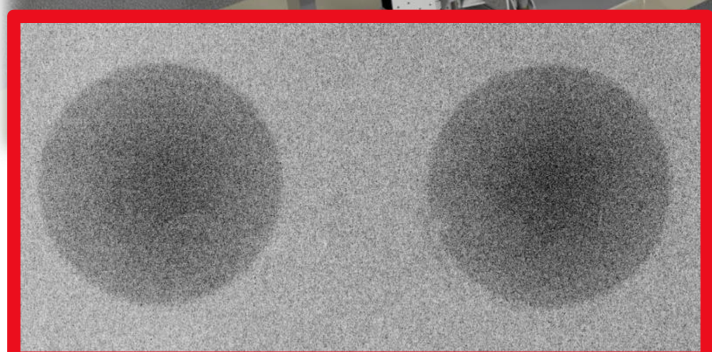
- Binocular mode of operation: Simultaneous measurement of sample in and out
- 2 non-parallel beam lines, 1mm in diameter that point to the same area on the neutron production target.
- No precise repositioning concerns, as long as the sample is precisely positioned beforehand: metrology network ~10μm and ~10 mdeg accuracy
  - Knowing where a pencil lead is positioned across the length of a basketball court
- Added bonus: measurements are completed in half the time!



Description of the apparatus

DICER: Device for Indirect Capture Experiments on Radionuclides

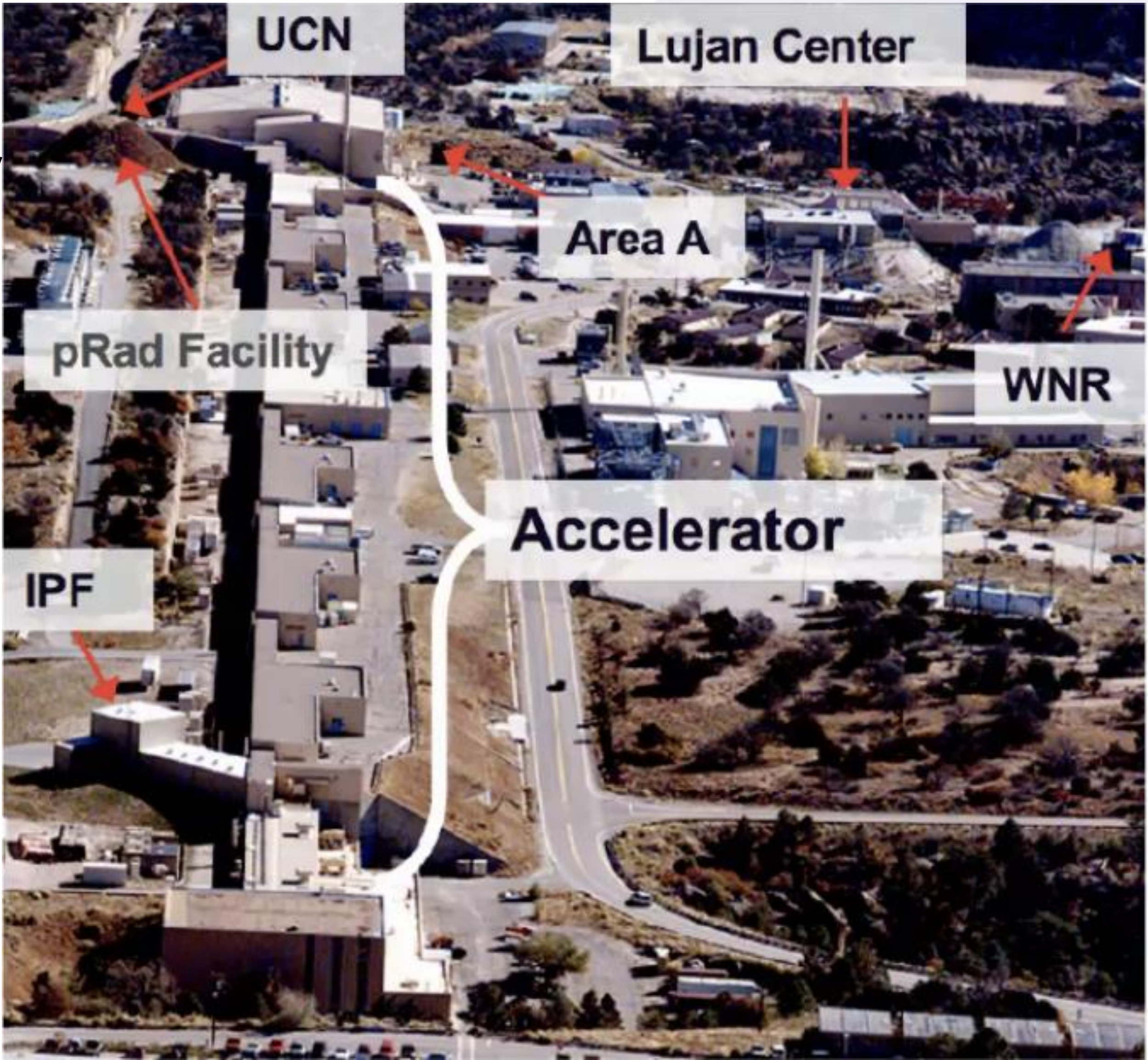




A. Stamatopoulos et al., NIMA (1025) 166166, 2022
A. Stamatopoulos et al., Neutron News 33, 12 – 14 (2022)
A. Stamatopoulos et al., IEEE Trans. Nucl. Science 70, (2023)

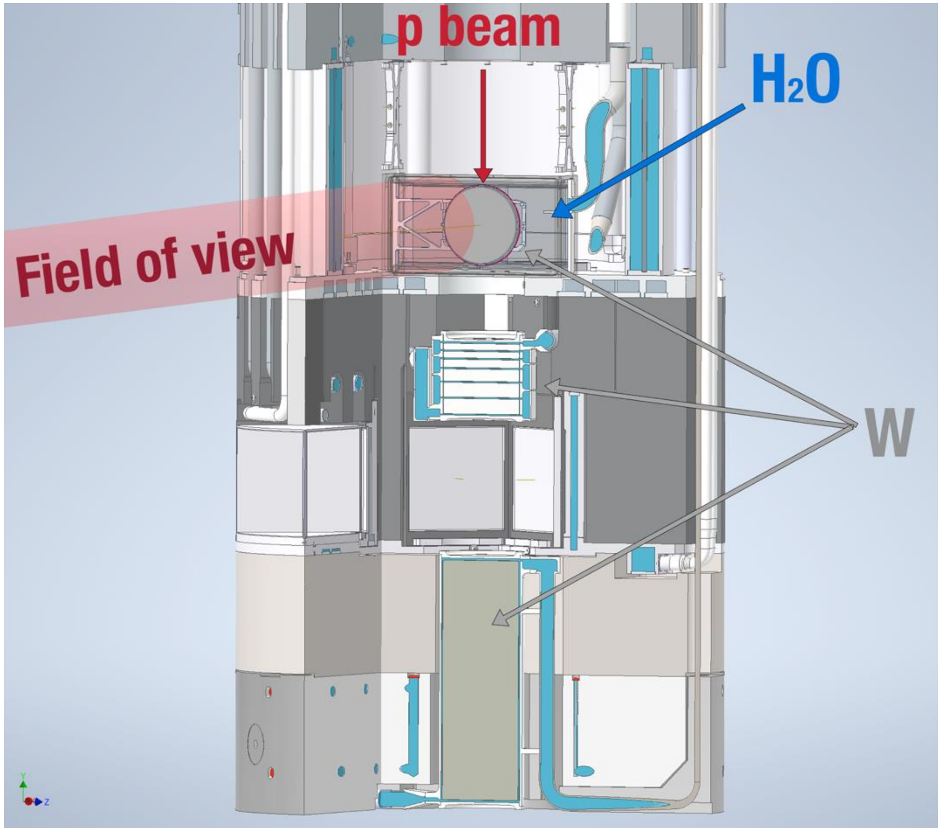
The where

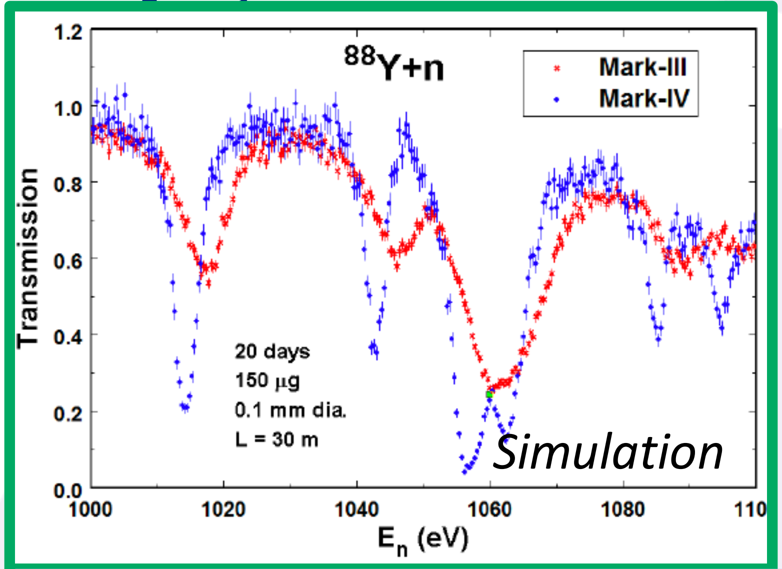
- LANSCE: The Los Alamos Neutron Science CEnter
- Multiuser facility with access to:
  - **Protons**
    - Isotope Production Facility (100 MeV)
    - Proton Radiation Facility (800 MeV)
    - Blue room (800 MeV)
  - **Neutrons**
    - Ultra Cold Neutron (neV)
    - Lujan Center (meV – 100 keV)
    - Weapons Neutrons Research (100 keV – 100 MeV)
- Production of radionuclides at IPF (~minutes-walk from Lujan)
- Sample fabrication at hot-cells at LANL (a few miles away from LANSCE)

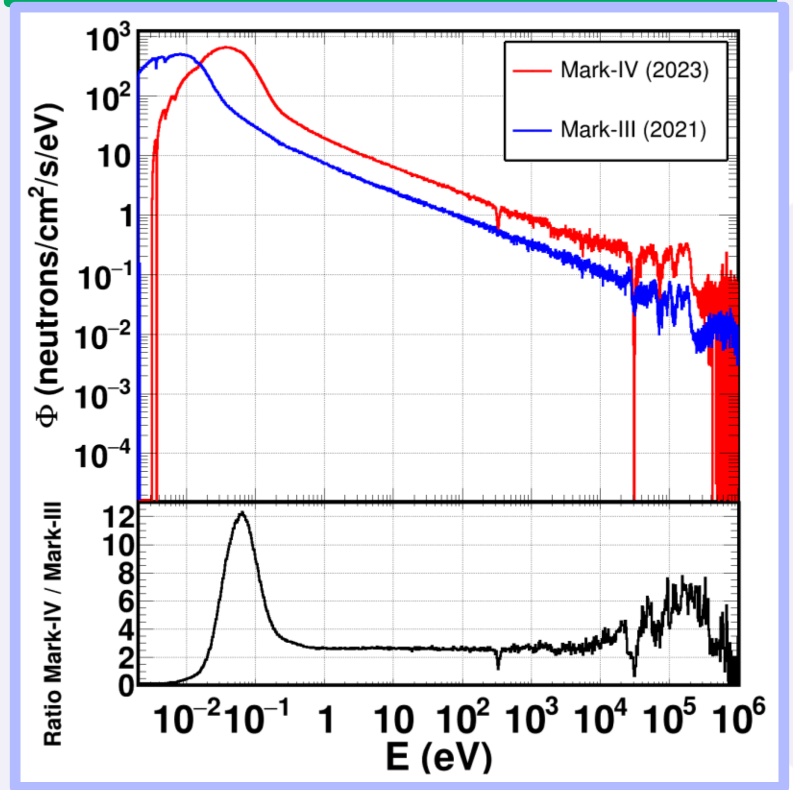


Mark-IV (M4) : New neutron target at Lujan, est. 2022

- 800MeV protons impinge on a W target
- Neutrons are produced through spallation
- A water moderator slows down neutrons
- Upgraded target-moderator assembly (Mark-IV) provides better **resolution**/**flux** than the previous generation (Mark-III)

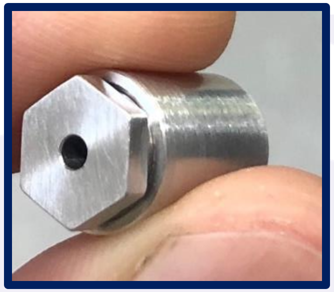




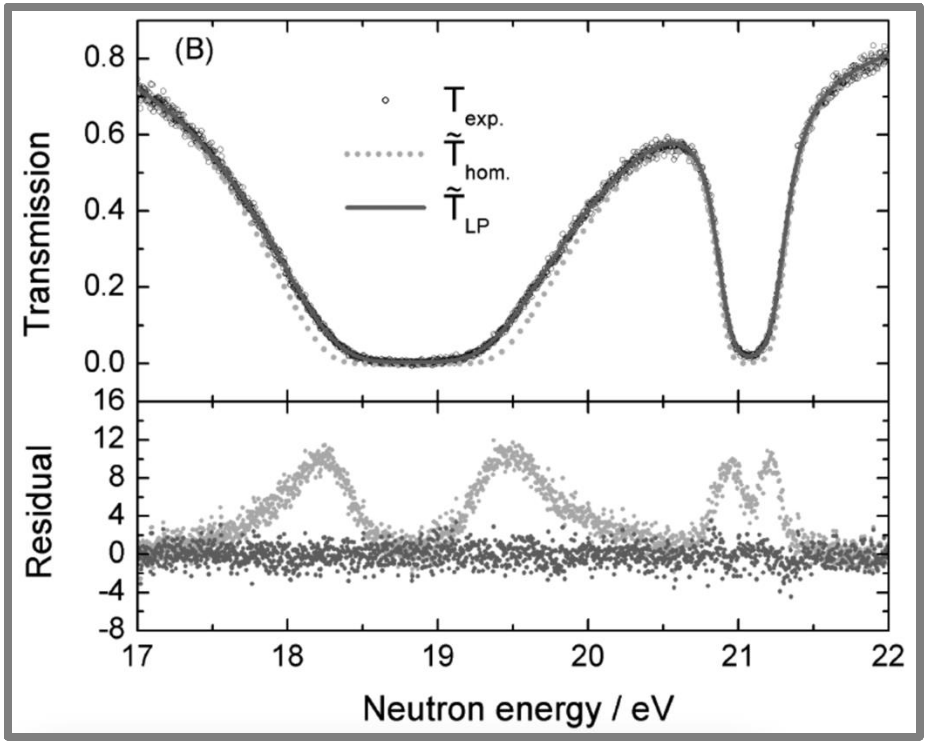


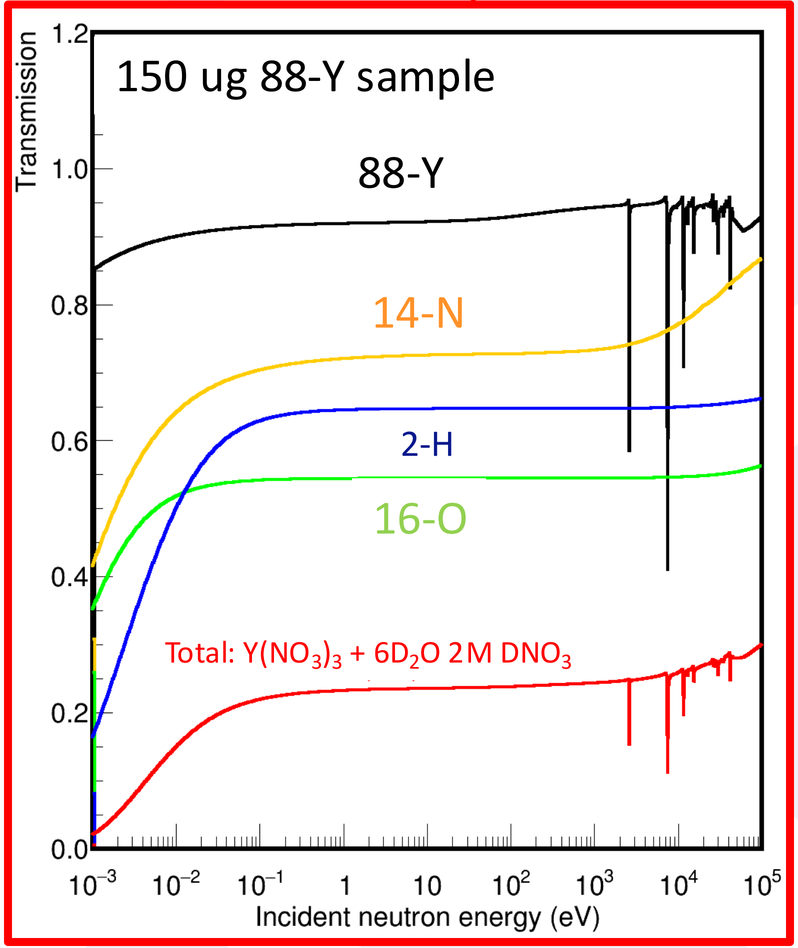
Importance of sample quality

Desired requirements for DICER samples



1. Samples should fit the DICER sample format (1/0.1 mm diameter, 1.5 cm length)
2. Uniformity and homogeneity
3. Minimization of hydrogen: replacement with deuterated compounds
4. Other components in the sample, should be transmission friendly: Avoid nuclei that are neutron absorbers.

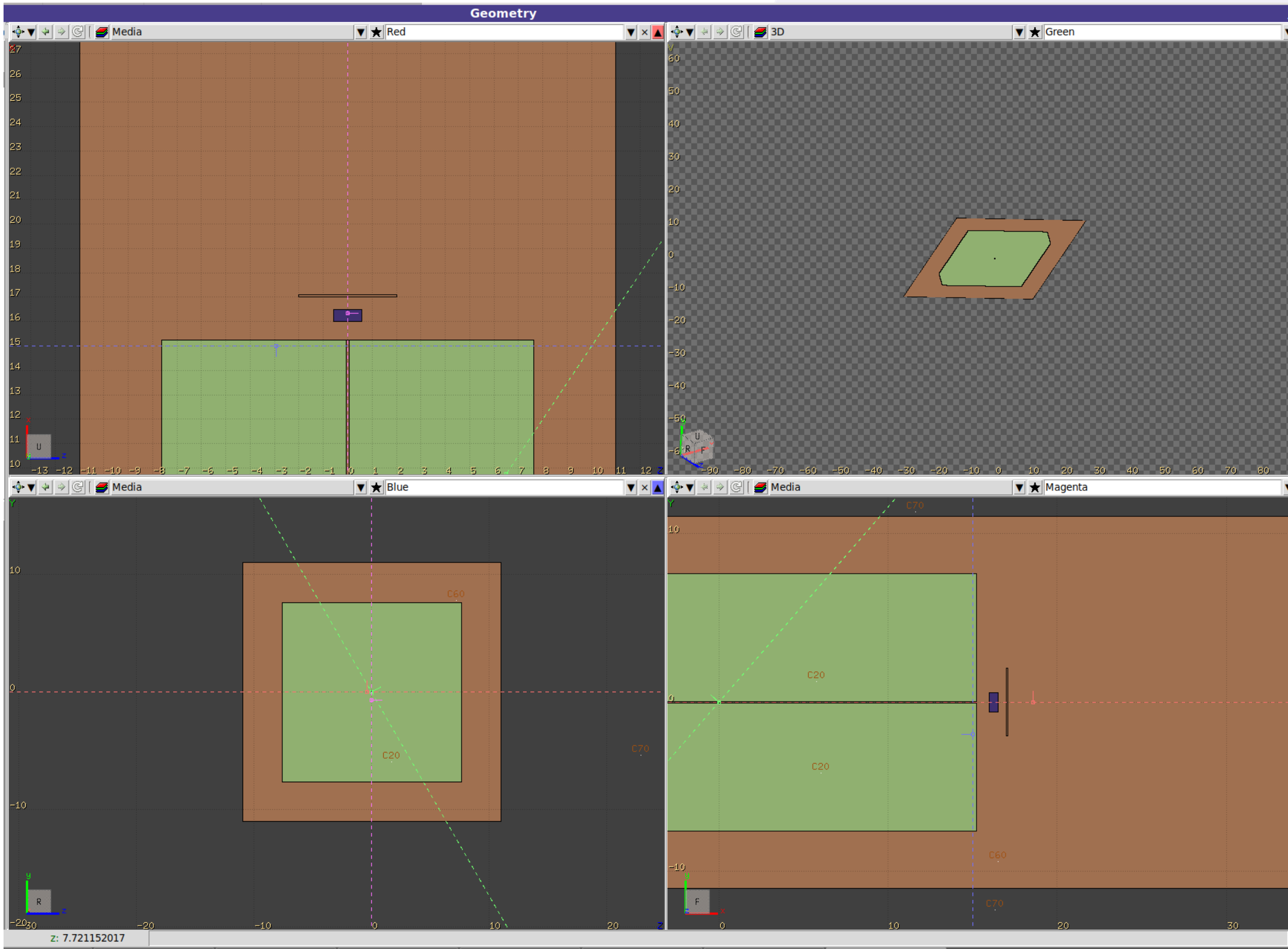




Experimental design and legacy samples: a ^{239}Pu case

- Sometimes we have legacy samples that can "almost" be used
- Example case of legacy ^{239}Pu samples that had less thickness than needed, combined
- Tilting the stack of sample would effectively increase the thickness
- Modeling the effect of stacking and tilting

- PARADIGM project
  - ML to identify experiments to speed up nuclear data evaluation and reduce uncertainties

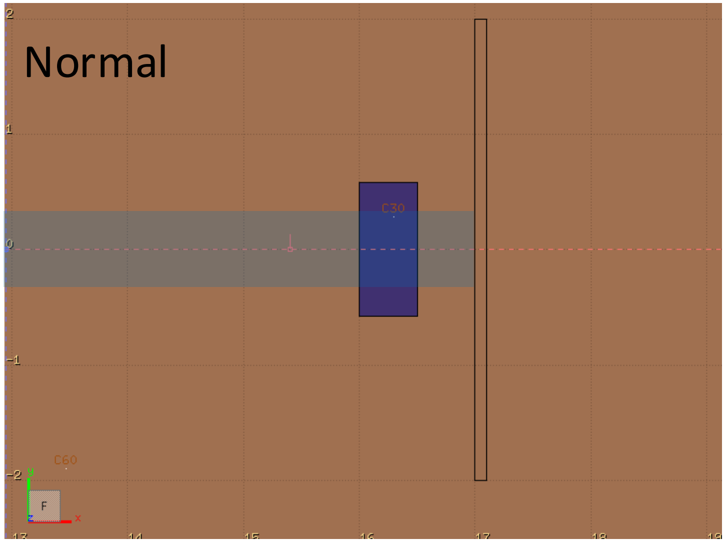


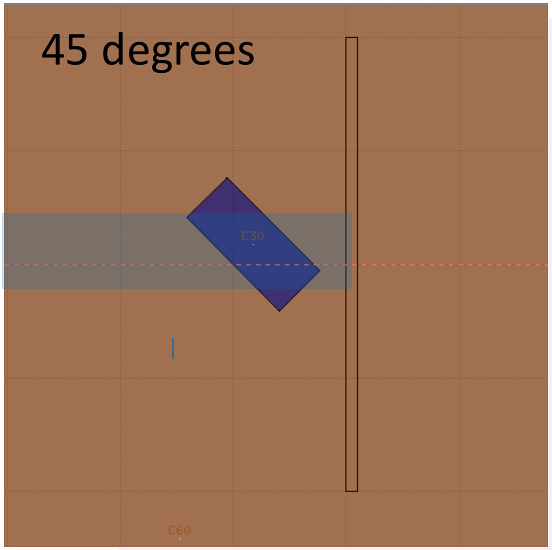
D. Neudecker et al. Phys. Rev. X, 15 021086 (2025) https://doi.org/10.1103/PhysRevX.15.021086

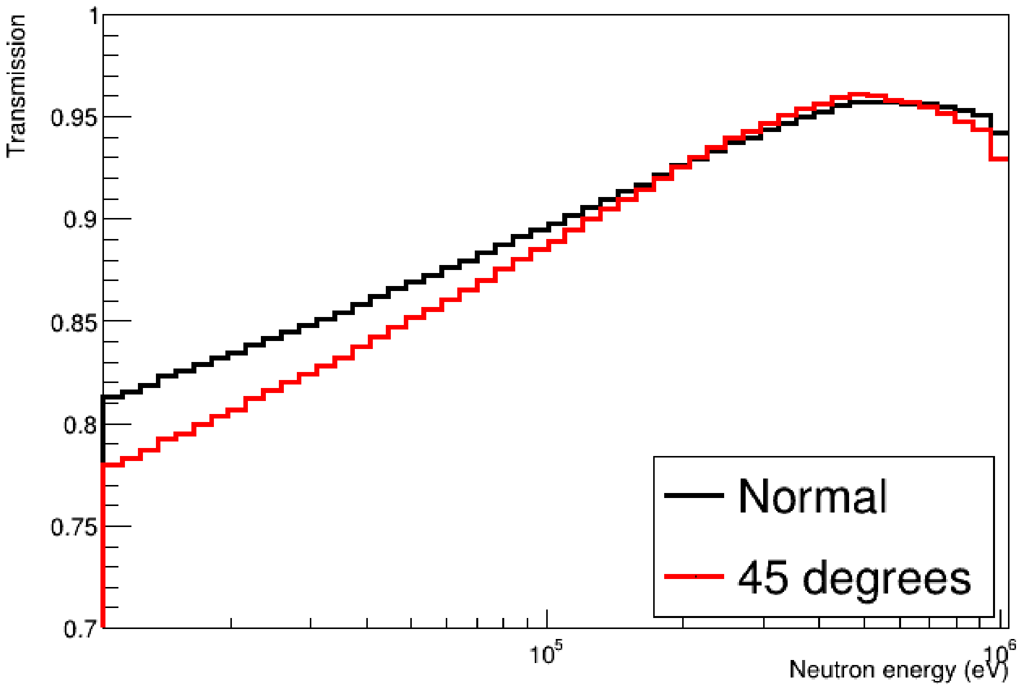
Los Alamos
NATIONAL LABORATORY

Experimental design and legacy samples: a ^{239}Pu case

- One of the cases was a 45-degree tilt

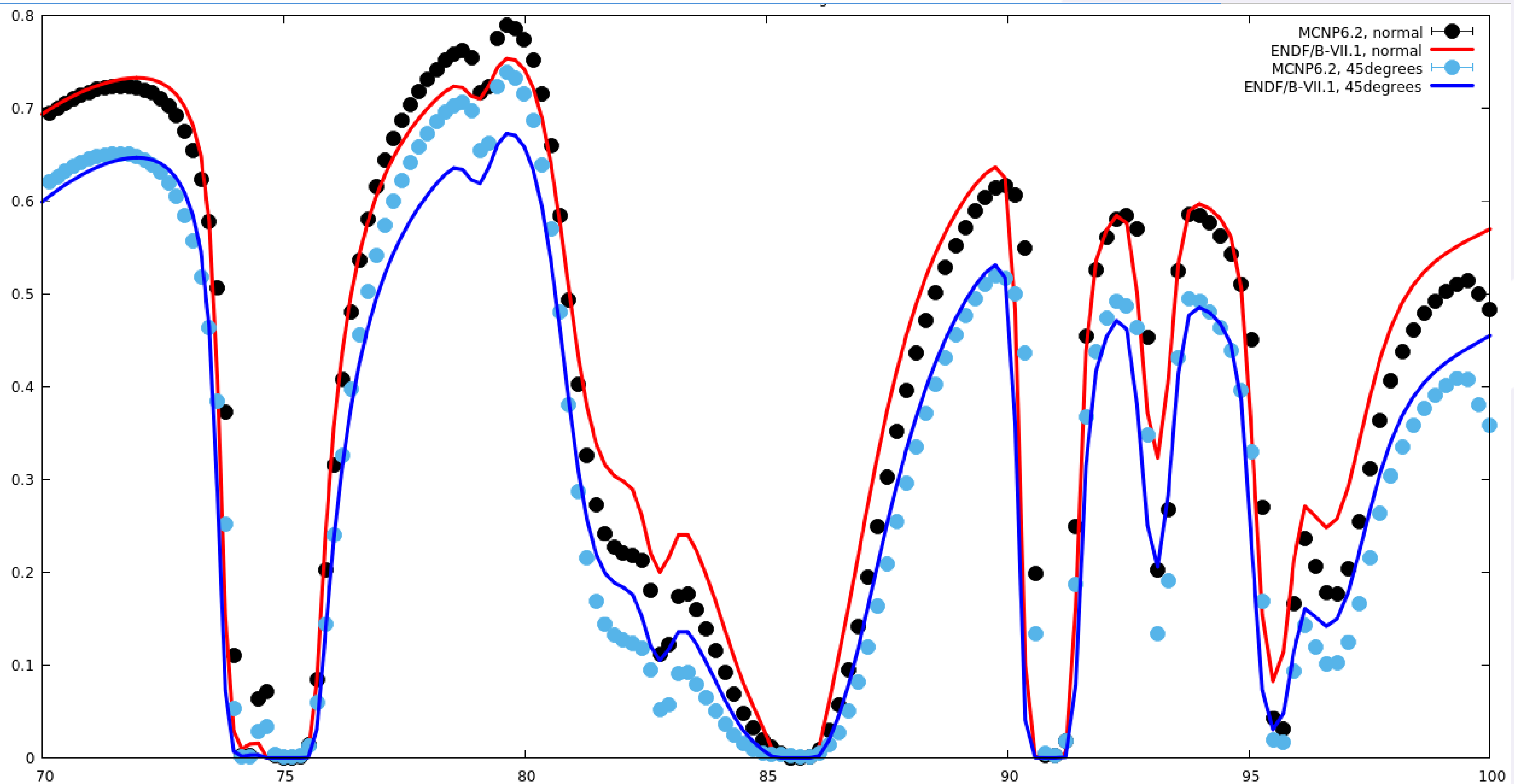






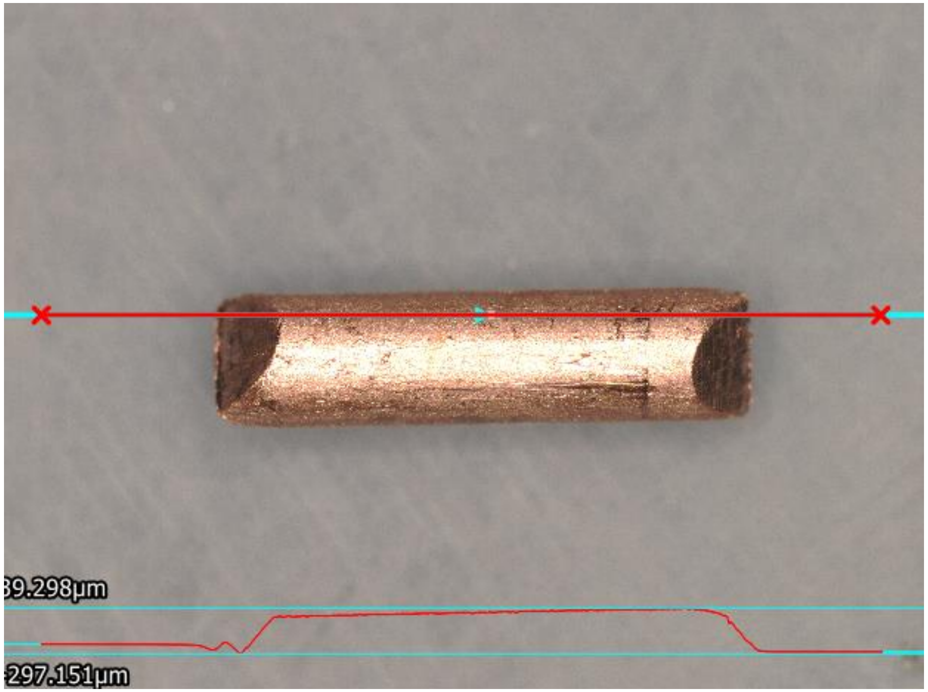
Experimental design and legacy samples: a ^{239}Pu case

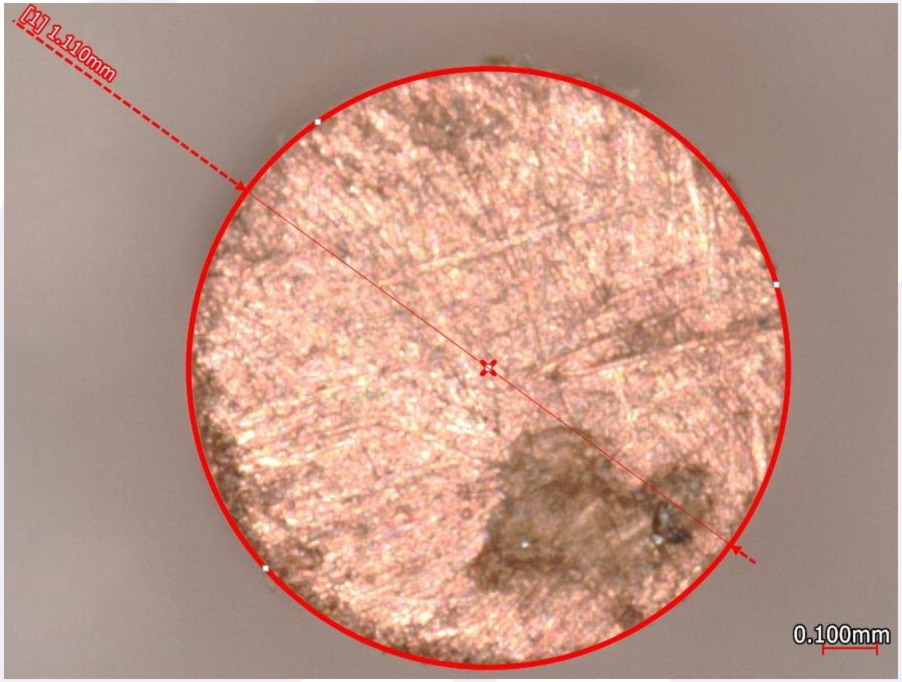
- Simulations in the resonance region



Experimental design: the ^{63}Cu case

- Isotopically enriched copper was cast into the DICER format, for PARADIGM
- Unfortunately, they cut the sample into the appropriate thickness with pliers
- MCNP simulations to assess the effect in the experiment





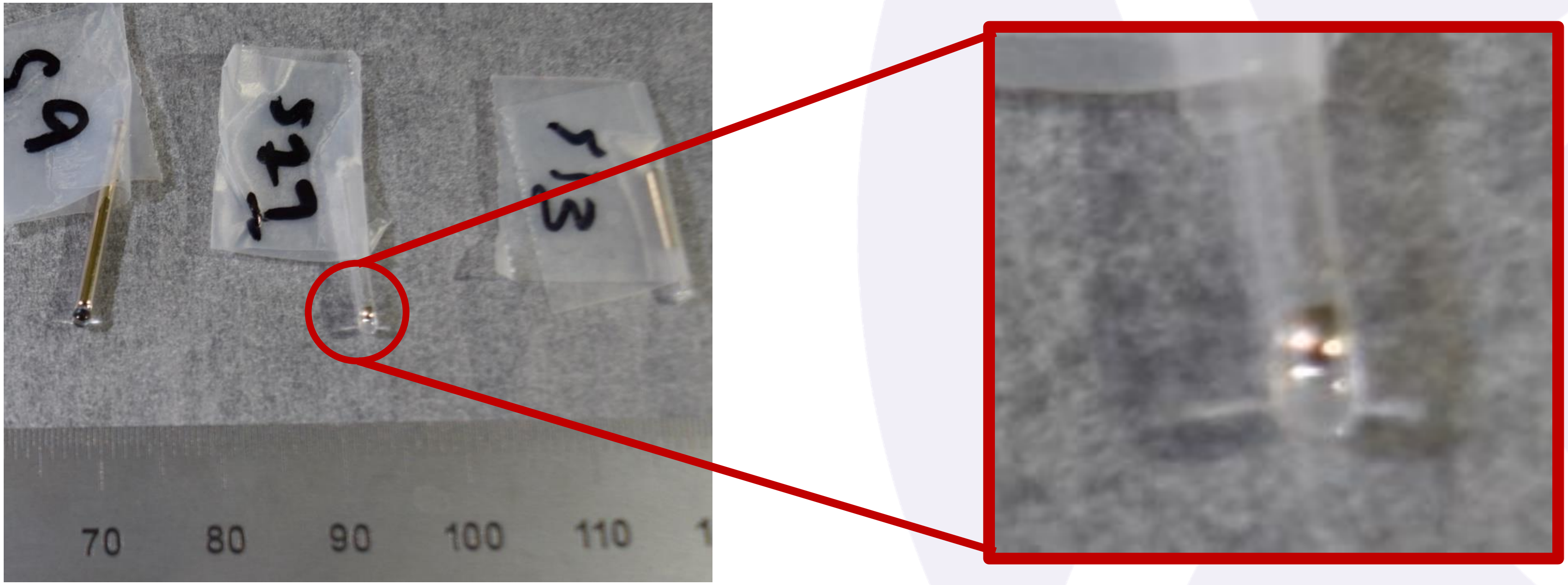
Experimental design: the ^{63}Cu case

- Isotopically enriched copper was cast into the DICER format, for PARADIGM
- Unfortunately, they cut the sample into the appropriate thickness with pliers
- MCNP simulations to assess the effect in the experiment

Simulations of tiny samples: The ^{133}Cs case

NCSP NUCLEAR CRITICALITY SAFETY PROGRAM

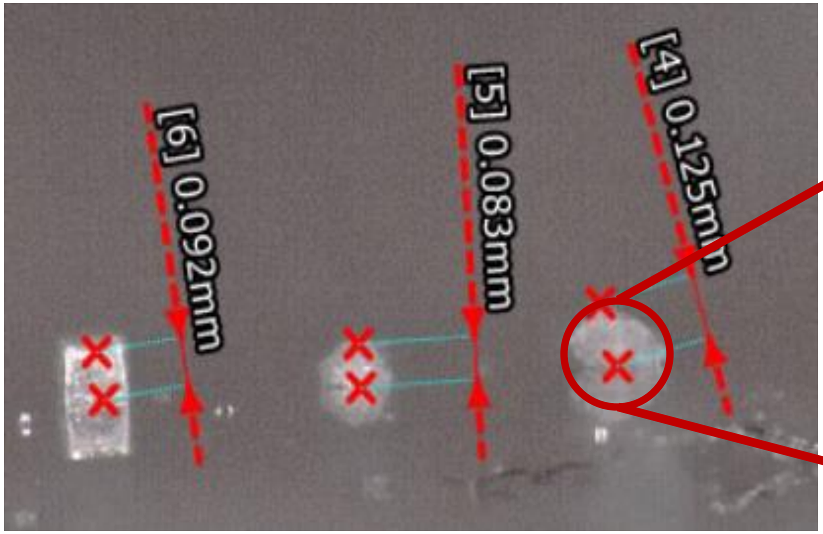
- Fission product
- Cs radionuclides (i.e. $^{134,\,135}Cs$) are important for radiochemical diagnostics
- Handle metallic Cs (pyrophoric) and shaping it in the DICER format is not trivial
- Start from natural that has a criticality safety interest
- Cs in flame-sealed capillary tubes (ORNL)
- **1.5**, 15, 25 mg
- Will be running simulations of rectangular vs spherical sample



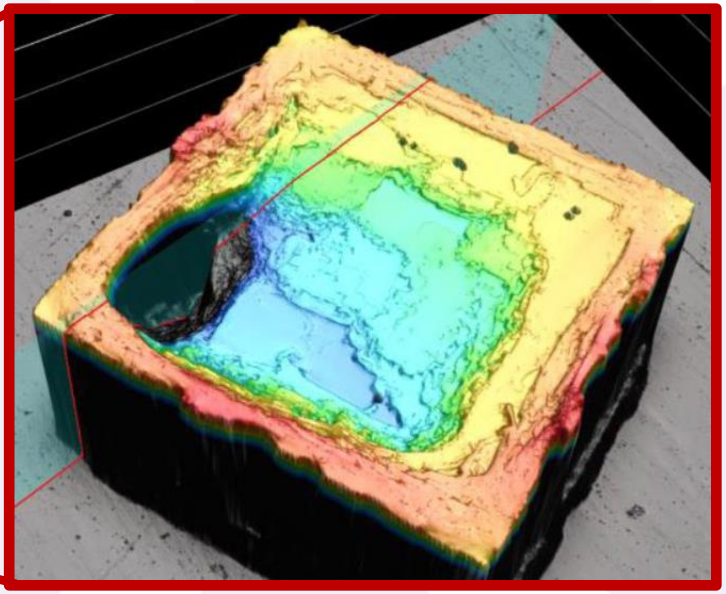
MCNP and sample fabrication: the 88Y case

- ^{88}Y is important for radiochemical diagnostics
- We estimate a 2 Ci (74 GBq) sample for this measurement
- This is only 150 ug and very challenging to acquire
- We need to develop a 0.1 mm collimator, new target fabrication and handling techniques
- 3D profilometry to inspect the samples (resolution ~A-um)
- Dream: go from the inspection images to MCNP modeling

Microjet printing

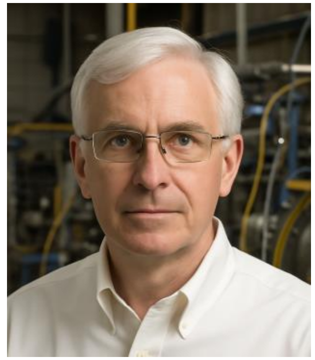


3D profilometer inspection



The teams

Thanos Stamatopoulos

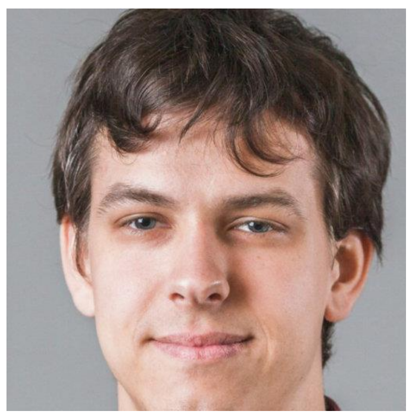


Matt Devlin
(AI generated)

Theresa Cutler

Denise Neudecker

Paul Koehler



Dusan
Kral

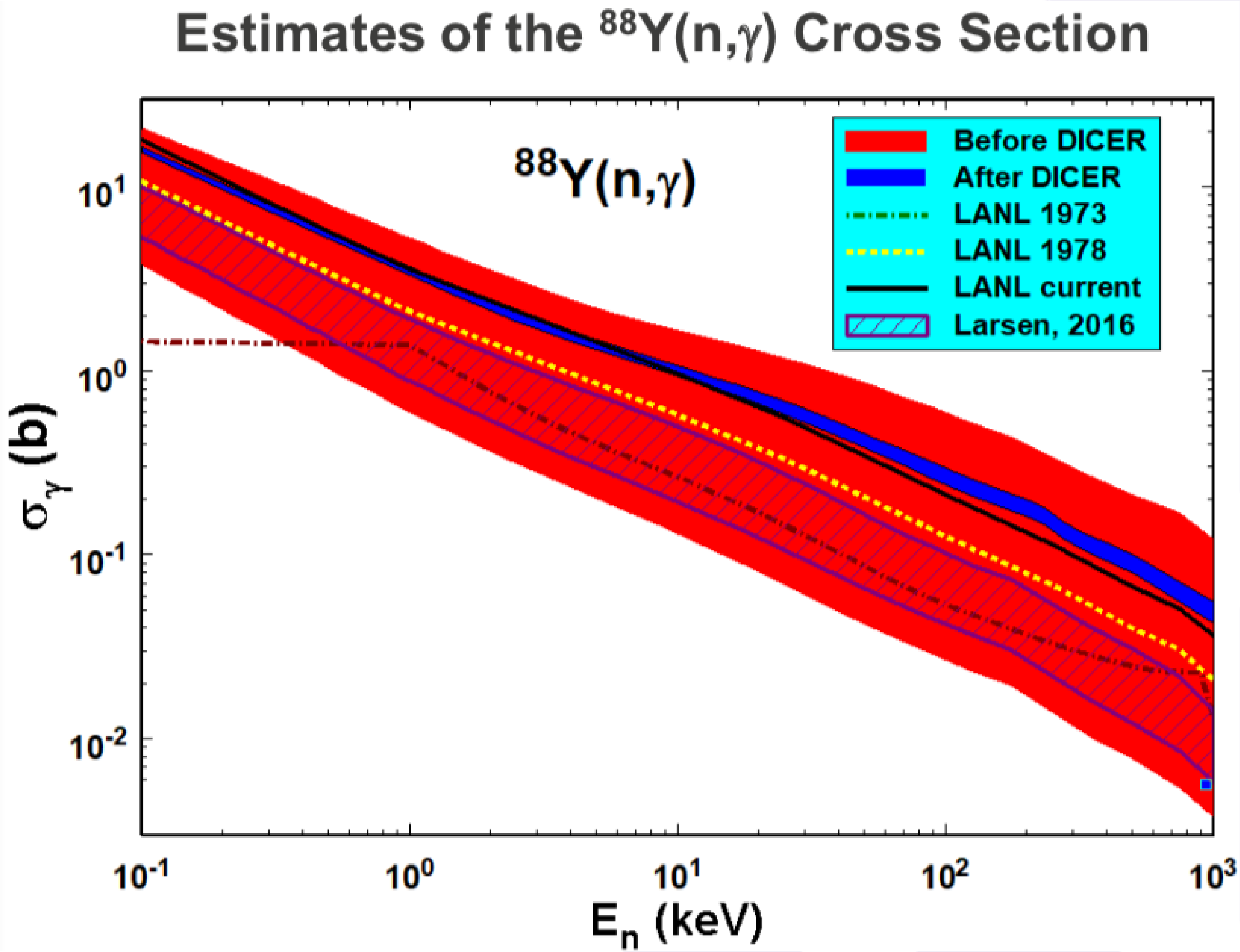
Josef
Svoboda

Andrew
Cooper

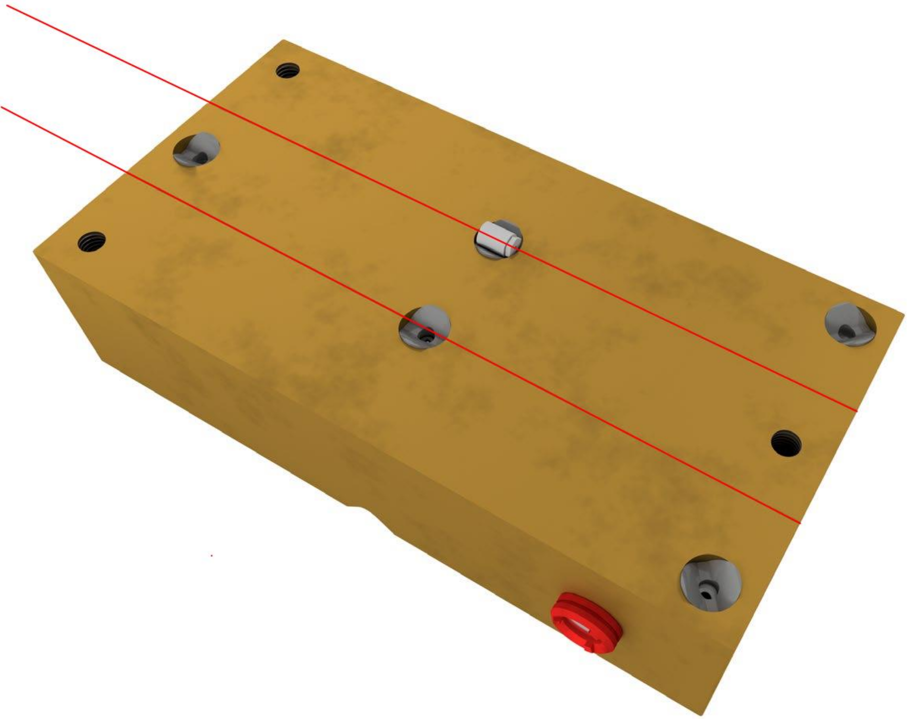

Thank you for
your attention!

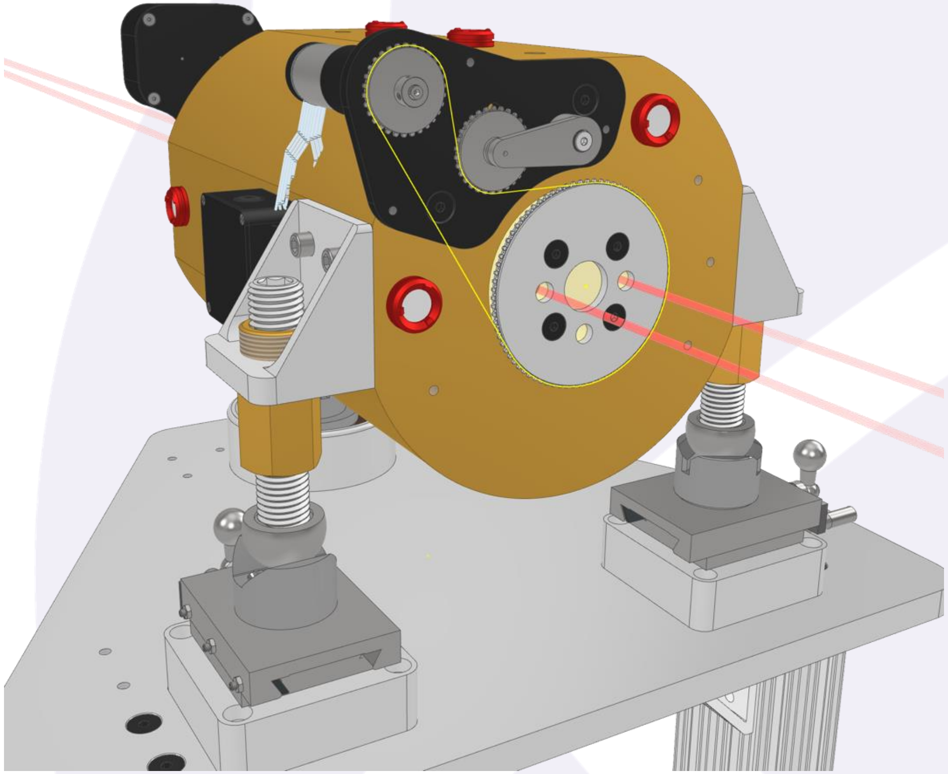
Back-up slides

^{88}Y



Estimates of the 88Y(n,γ) Cross Section
88Y(n,γ)
Before DICER
After DICER
LANL 1973
LANL 1978
LANL current
Larsen, 2016
σγ (b)
10^1
10^0
10^-1
10^-2
10^-1
10^0
10^1
10^2
10^3
En (keV)





Different masses → different thicknesses (**0.6 mm**, **5.9 mm**, **11.8 mm**)